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NUCLEAR HEALTH AND SAFETY

Better Earthquake Protection Needed at DOE's Savannah River Site

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Resources, Community, and
Economic Development Division

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December 26, 1989

The Honorable Mike Synar
Chairman, Environment,
Energy and Natural
Resources Subcommittee
Committee on Government Operations
House of Representatives

Dear Mr. Chairman:

On October 6, 1988, you requested that we examine the Department of Energy's (DOE) ability to ensure employee and public safety in the event of a major earthquake at its Savannah River site. Seismic questions are among numerous safety issues that have been raised over the last year concerning the site, located near Aiken, South Carolina. Public and congressional concern has focused on the capability of the site's three aging nuclear reactors to safely produce nuclear materials for the national defense. The reactors are currently shut down for safety reviews and modifications. DOE plans to restart the reactors as soon as possible—the most recent estimate is to begin producing tritium in the first reactor in late 1990—and operate them until a new reactor is built and tritium is extracted, which is estimated to take over 12 years.

The earthquake potential at Savannah River is based mainly on the fact that a large earthquake—estimated to have been the equivalent of about 7 on the Richter scale—occurred in South Carolina in 1886, centered about 80 miles east of the site near Charleston. The event caused devastation and considerable loss of life in that city.

Our review focused on DOE's efforts to ensure adequate seismic safety at Savannah River. It is a key site for supplying U.S. defense requirements for tritium and plutonium for nuclear weapons. The three reactors—K, P, and L—that produce these materials, as well as other facilities that process them, are considered high-risk facilities because of the dangerous radiation they could potentially release into the environment. DOE's Assistant Secretary for Defense Programs has line-safety-management responsibility for these facilities, and the Assistant Secretary for Environment, Safety, and Health (ES&H) has had internal DOE safety oversight responsibilities, though this office's role is evolving under a recently announced DOE reorganization plan. Additional oversight is provided by the Advisory Committee on Nuclear Facility Safety established by DOE in December 1987 to provide technical advice on DOE's nuclear

facilities, including the restart of the reactors at Savannah River, and the newly established Defense Nuclear Facilities Safety Board, mandated by the Congress in 1988.[1]

Results in Brief

As in other areas of nuclear safety, DOE has only begun in 1988 and 1989 to take a systematic approach to correcting seismic problems that have existed at Savannah River for years. No comprehensive program to systematically assess the seismic safety of the reactors and other nuclear facilities has been in place at the site. As a result, some safety-related systems, equipment, and structures do not meet current standards, and others have not been evaluated to determine if they meet the standards. Numerous systems and structures in the reactors and other nuclear facilities may not withstand the worst earthquake reasonably expected at the site and, in the event of such an earthquake, could threaten employees and the public with releases of radiation.

As an interim corrective step necessary to restart the reactors, DOE has undertaken expedited seismic inspections and modifications of the reactors in 1988 and 1989. After doing some inspections in 1988 based on less stringent engineering standards than the Nuclear Regulatory Commission requires for designing new commercial reactors, DOE has since done followup reinspections in 1989 based on more stringent standards. In addition, the earlier inspections were not always subjected to adequate independent oversight. For example, in 1988 DOE's Office of the Assistant Secretary for ES&H guided seismic planning related to the reactors' restart because of limited DOE seismic expertise in the line-management organization. ES&H's involvement in operational planning impaired its ability to independently oversee the effort.

DOE recognizes the need for a long-term, comprehensive approach to the seismic safety of its reactors and other high-risk facilities at Savannah River. According to DOE and contractor officials, planning is under way to approve and implement in phases a comprehensive seismic program for the reactors and other facilities at the site. While this is a start, it will take several years to accomplish adequate seismic protection at Savannah River. Timely, sustained implementation of a seismic program will be a necessary part of DOE's overall efforts to operate the site safely.

[1] In May 1989, the Secretary of Energy announced a reorganization affecting several DOE organizations having responsibility for nuclear safety. These changes are discussed on page 7.

Facilities Have Seismic Weaknesses

The worst earthquake reasonably expected to occur at Savannah River is based mainly on the potential recurrence of the major earthquake near Charleston, South Carolina, of 1886. Seismic-engineering standards for the site based on the earthquake did not exist in the early 1950s when the reactors were built. The standards have been established (and updated) only since 1967. According to site contractor evaluations, Savannah River's reactors and nuclear materials processing facilities have numerous weaknesses in seismic reinforcement of structures, systems, and equipment. These problems could potentially cause radioactive releases in a major earthquake, placing employee and public health and safety at risk.

DOE evaluations have found many bracing problems in the reactors, including weaknesses in piping and equipment supports in the primary and secondary cooling water systems, the emergency core-cooling system, and the radioactivity confinement system. K and L reactors' vent stacks have also been determined by DOE to be inadequately supported. DOE is analyzing these weaknesses and undertaking modifications in preparation for restarting the reactors, while other modifications will be done in the future. In addition, site safety analyses indicate that several nuclear-processing facilities, such as the existing tritium-loading facility, have seismic weaknesses that would be of serious concern in a major earthquake.

Problems With 1988 Seismic Inspections

In 1988 and 1989, Savannah River has undertaken expedited seismic inspections to prepare its production reactors to be restarted. The seismic inspection of P reactor in the summer of 1988 used modified NRC procedures, was based on less stringent engineering standards than NRC requires for designing new commercial reactors, and had several implementation problems. K and L reactors were inspected in October 1988 under more rigorous procedures, but a confirmatory reinspection of them was required in 1989, on the basis of updated engineering standards more consistent with NRC requirements. As a result of the inspections, many seismic modifications are planned, under way, or completed.

P Reactor Inspection

Prior to its expected restart in the summer of 1988, P reactor was inspected for seismic deficiencies, and dozens of upgrades of its seismic bracing were made. To expedite the process, a number of trade-offs in requirements were made. For example, DOE adapted for its use NRC seismic inspection procedures. The procedures called for engineering teams to walk through the reactor and assess the resistance of a minimum

number of essential structures, systems, and pieces of equipment to the worst earthquake reasonably expected at the site. The effort was intended as an interim step to rapidly ascertain the capability of critical functions in the reactor that might require immediate seismic upgrading. More complete evaluations were to be done after the reactor was operational.

DOE Savannah River Operations Office and contractor officials had decided that existing seismic-engineering standards established for the site in previous years were adequate as a basis for the interim inspection. Such standards estimate the motions of the worst earthquake reasonably expected at the site, as well as the response motions of buildings, and are used to design buildings to withstand these motions. DOE ES&H officials questioned whether these standards were stringent enough in comparison to current NRC standards for designing new commercial reactors, but agreed that with some changes, they could be used for the inspections as long as the standards were reevaluated in the future. ES&H officials also questioned the adequacy of the reactors' existing engineering analyses of record, which are used, among other things, to support judgments that the reactors can be operated safely. However, they deemed that despite inadequate existing analyses, an effective interim inspection could be undertaken to allow the reactor to be safely restarted.

The inspection process itself had several problems. For example, because as-built engineering drawings were inadequate, DOE chose in many cases not to do engineering analyses to support assessments made (as called for in the NRC inspection procedures), relying instead on expert engineering judgments by the inspection teams. In addition, DOE chose in many instances not to physically test the strength of seismic bracing in the reactor. Furthermore, during the inspection, the inspection teams inadvertently used an incorrect, less-stringent-than-intended engineering factor for estimating how the reactor would absorb the effect of an earthquake. P reactor is to be reinspected in early 1990 using more stringent seismic-engineering standards.

DOE approved the restart of P reactor in August 1988, unaware of the misapplied engineering factor, which was discovered in September. The restart was aborted for reasons unrelated to seismic safety—there were operational errors in responding to a restart anomaly, which was compounded by the incident's not being properly reported to DOE. As DOE reviewed the problems that aborted the restart, it found more seismic

and other safety issues needing attention. The contractor is implementing a June 1989 plan for addressing these issues.

K and L Reactor Inspections

DOE turned to K reactor in September 1988 as the first reactor to be restarted, and originally projected its startup to occur at the end of 1988. Seismic inspections of the reactor proceeded in October and November of 1988. L reactor was also inspected at this time. For these inspections, DOE ascertained the interim capability of critical reactor functions as with P reactor, but the inspection procedures used were more stringent. As a result, the K and L reactor inspections were more rigorous, with more physical testing of bracing as well as engineering analysis to support the assessments of the inspection teams.

After the K and L reactor inspections, DOE addressed the adequacy of the site's engineering standards. In late November 1988, DOE and the site contractor agreed on new standards for how the reactor might respond in an earthquake. These standards were based in part on existing, more rigorous standards in NRC guidance. A consultant was hired to do new engineering analyses required to verify the K reactor building's response in the worst earthquake reasonably expected at Savannah River. Consultant work was completed and used for confirmatory seismic reinspections of K and L reactors in 1989. According to DOE officials, this analysis and the subsequent reinspections were carefully done, and resulted in assessments of systems and equipment resistance that were generally in line with those of the previous inspections in the fall of 1988. On the basis of these inspections and reinspections, many deficiencies in major safety-related systems in K reactor have been identified, and modifications are under way.

No Comprehensive Seismic Program in Place

Over the years, there has been no systematic program in place at Savannah River to ensure that seismic standards are updated and appropriately used, or DOE criteria to assess when and how systems and structures should be upgraded to meet the updated standards. As engineering standards for building construction have become more stringent, the Savannah River contractor has revised its seismic standards. However, in some cases during the 1980s the contractor used older engineering standards as a basis for seismic upgrades. In addition, while some structures and systems have been seismically upgraded, other structures and systems—some safety related—have not been evaluated to determine if they meet current seismic-engineering standards. The result

has been a piecemeal approach to seismic protection of the site's facilities.

In connection with reactor restart planning, in 1989 the new site contractor developed a long-term seismic program plan for the reactors, which is under review by DOE. According to DOE officials, the plan proposes a comprehensive approach to seismic safety for the site's reactors, and its scope and intent have been approved. Its details are to be approved and implemented in phases in coming months and years, but interim seismic planning related to restarting the reactors is now the highest priority. The contractor is also drafting plans to include other high-risk nuclear facilities at the site in a similar long-term program.

Oversight Issues

The process of upgrading the reactors' seismic adequacy for restart has at times not been subjected to adequate independent oversight. Oversight by an independent, technically competent group helps to ensure, among other things, that the DOE line organization and the contractor are considering current engineering standards and appropriately applying them.

Questions of oversight were especially prominent in relation to the attempted restart of P reactor. In June 1988, to prepare for the restart, DOE chose to upgrade a minimum number of key reactor functions that in its view would safely shut down the reactor in a major earthquake. Additional important upgrades were to be done within a few years. ES&H had a major role in making this decision. DOE officials told us that ES&H's decision-making role was necessary because of the need to expedite the startup of the reactor and the lack of resources and expertise in DOE's line-safety-management organization. At the same time, however, this role lessened ES&H's ability to perform its independent oversight role. In addition, the Secretary of Energy's Advisory Committee on Nuclear Facility Safety was not fully organized at the time and did not participate actively in overseeing the decision.

Early in the K reactor restart process, ES&H continued to be involved in line-management responsibilities as well as performing its oversight role. According to DOE officials, however, in 1989 ES&H assumed less of an operational posture during restart efforts.

The Advisory Committee has had an active oversight role in the K reactor restart process. In regard to seismic issues, the Committee has focused on the K reactor functions that need upgrading to ensure safe

shutdown in a major earthquake. DOE plans to upgrade a minimum number of key reactor functions, with additional upgrades to be done in the future. However, the committee has questioned DOE's justification for this approach and has requested that DOE support its position through risk assessments. According to DOE officials, such assessments are ongoing and scheduled to be completed before K reactor is restarted.

On May 19, 1989, the Secretary of Energy issued guidance indicating the apparent shift of some headquarters and field nuclear safety oversight functions from ES&H to the Assistant Secretaries for Defense Programs and Nuclear Energy. In addition, DOE decided that much of the Advisory Committee's nuclear safety oversight role would cease when the congressionally mandated Defense Nuclear Facilities Safety Board becomes more established. Subsequent to the May guidance, the Secretary created an Office of Nuclear Safety, reporting directly to him, which will have broad responsibilities to monitor and audit all aspects of nuclear safety. According to DOE, the Secretary's reorganization has been implemented as it relates to Savannah River restart activities, but it may not be fully implemented DOE-wide for many months because DOE resources are lacking. It remains to be seen how these changes will affect the quality of internal DOE and external safety oversight as preparations to restart K reactor continue.[2]

Conclusions

DOE faces an enormous challenge in restarting the Savannah River production reactors as well as ensuring that all nuclear facilities at the site are operated in a safe manner. Part of the challenge is ensuring that the buildings and equipment meet seismic standards which protect site workers and the public in the event of an earthquake. However, numerous systems and structures—in the reactors as well as other high-risk nuclear facilities—may not withstand the worst earthquake reasonably expected at the site. Important facilities at Savannah River were built to standards that have been superseded, and DOE has not had a systematic program to ensure upgrading to the latest standards where appropriate.

DOE recognizes the need for a more comprehensive, sustained approach to the seismic safety of its reactors and other high-risk nuclear facilities and has made upgrades to the reactors as an interim step in 1988-89. DOE is planning to phase in a long-term seismic program for Savannah River's reactors in coming months and years, and is planning to include

[2]At your request, we are evaluating the impact of this reorganization and will present the results to you in the near future.

other site facilities in a similar program. The development of such a program is important to the continued safe operation of the nuclear facilities at Savannah River, and timely implementation of it is equally important. To help ensure such implementation, we believe adequate independent oversight of such a program will be necessary for its success.

Recommendations

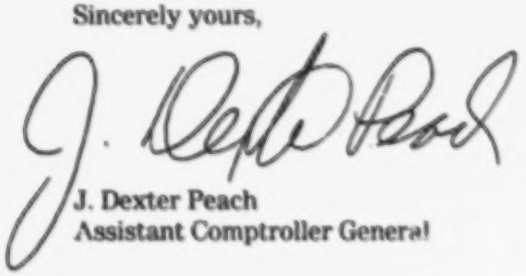
To help ensure employee and public safety in the event of a major Savannah River site earthquake, we recommend that the Secretary of Energy establish a comprehensive, systematic seismic program for the reactors and other high-risk nuclear facilities at Savannah River. The program should include updating of seismic criteria and site engineering standards as necessary, as well as appropriate ongoing independent oversight to help ensure its adequacy and timely implementation. Further, because earthquake potential exists at other locations, we recommend that the Secretary conduct an examination to determine the need to upgrade seismic programs at DOE locations with high-risk nuclear facilities.

Our review examined criteria DOE has developed for earthquake safety, as well as NRC criteria for earthquake safety which DOE has adopted, although it is not subject to NRC regulation. In addition, we examined DOE, U.S. Geological Survey, and NRC analyses of the risk of a major earthquake at or near the site and the ability of DOE's nuclear facilities there to withstand such an event. We also examined numerous DOE program documents related to site seismic safety and interviewed DOE, Advisory Committee on Nuclear Facility Safety, and contractor officials at headquarters and in the field. A more detailed discussion of the objectives, scope, and methodology of this review is included in appendix I.

We discussed the contents of this report with agency officials as it was being developed and incorporated their views as appropriate. As requested, we did not obtain official agency comments on a draft of this report. The review was done in accordance with generally accepted government auditing standards. Unless you publicly announce its contents earlier, we do not plan to distribute this report until 30 days from the date of this letter. At that time, we will send copies to the Secretary of

Energy and other interested parties. This report was prepared under the direction of Keith O. Fultz, Director, Planning and Reporting, former Director of Energy Issues. Victor S. Rezendes, the current Director of Energy Issues, may be reached on (202) 275-1441. Other major contributors to this report are listed in appendix V.

Sincerely yours,



J. Dexter Peach
Assistant Comptroller General

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Abbreviations

DOE	Department of Energy
ES&H	Assistant Secretary for Environment, Safety, and Health
GAO	General Accounting Office
NRC	Nuclear Regulatory Commission

Introduction

The operational safety of three production reactors at the Department of Energy's (DOE) Savannah River site, located near Aiken, South Carolina, has become a major public issue, and the reactors are currently shut down. DOE is reviewing various aspects of reactor operations and is making many changes, including reactor modifications, before deciding that production can be safely resumed. Among the necessary modifications are improvements in seismic reinforcement to correct numerous deficiencies identified in 1988 and 1989 seismic inspections of the reactors. These deficiencies are based on the potential of a major earthquake occurring on-site. This risk has been calculated to be less than 1 predicted occurrence every 1,000 years, but is still being studied.

Background

Savannah River produces nuclear materials for defense-related purposes. It is a key DOE site for supplying Department of Defense requirements for tritium and plutonium for nuclear weapons. Three over-35-year-old nuclear reactors at Savannah River are the only production sources of one of these materials—tritium—to meet U.S. needs until a new production reactor can begin to operate at the site and extract tritium, which is estimated to take over 12 years.

The site was operated by E.I. DuPont de Nemours and Company for the government until April 1, 1989, when the Westinghouse Savannah River Company became the contractor. Site operations include fabrication of enriched uranium and other materials into nuclear fuel, irradiation of this fuel in a reactor, and extraction of usable material from the irradiated (or spent) fuel in a reprocessing facility. In addition, the site has facilities for storing radioactive wastes, research and process development, and other activities. The reactors and several processing facilities are considered high risk because of the dangerous radiation they could potentially release into the environment.

Westinghouse, DOE's Savannah River Operations Office, and DOE's Assistant Secretary for Defense Programs are charged with line-safety responsibilities for the site. In addition, DOE's Assistant Secretary for Environment, Safety, and Health (ES&H) has some oversight responsibilities relating to the site, though this office's role is evolving under a recently announced DOE reorganization plan. In December 1987, DOE also established the Advisory Committee on Nuclear Facility Safety, which is tasked with providing technical advice on health and safety matters at Savannah River and other nuclear defense complex facilities. In addition, in 1988 the Congress passed legislation establishing the Defense

Nuclear Facilities Safety Board to oversee the safety of sites such as Savannah River. The board is now being put in place.

In May 1989, the Secretary of Energy announced a reorganization under which some headquarters and field nuclear safety oversight responsibilities would shift to the Assistant Secretaries for Defense Programs and Nuclear Energy. DOE has also decided that much of the Advisory Committee's nuclear safety oversight role would cease when the Defense Nuclear Facilities Safety Board becomes operative. Subsequent to the May announcement, the Secretary created an Office of Nuclear Safety reporting directly to him which will have broad responsibilities to monitor and audit all aspects of nuclear safety. According to DOE, no shifts will take place until Defense Programs, Nuclear Energy, and the board are staffed and ready to receive their new responsibilities. The Secretary's reorganization has been implemented for Savannah River restart operations, but is not expected to be fully implemented DOE-wide for many months because funds may not be available in fiscal year 1990 to fully staff the DOE organizations.

The three producing reactors at the site—K, P, and L—have not operated since the spring of 1988. In August 1988, the contractor attempted to restart P reactor, but problems with the restart caused the reactor to be shut down and led to a DOE safety review of technical, human performance, and management issues related to restarting the reactors. That review is ongoing and may continue for several more months. The contractor is implementing a plan for resolving these issues. DOE turned to K reactor in September 1988 as the first to be restarted. Seismic inspections of the reactor have been undertaken, and modifications are under way. According to the most recent estimate, K reactor is to be restarted and begin producing tritium in late 1990.

Earthquake Risk at Savannah River Is Under Study

DOE and other studies confirm that there is a degree of risk of a major earthquake's occurrence at Savannah River. The risk has been calculated to be less than 1 predicted occurrence every 1,000 years, but the scientific community continues to study the risk because of an incomplete understanding among geologists of the fault zones that could have caused the 1886 Charleston earthquake, the major event on which the seismic risk to Savannah River is based.

Various analyses have examined the earthquake risk at or near Savannah River. The Nuclear Regulatory Commission (NRC) and the U.S. Geological Survey have studied the risk of an earthquake at or near

Savannah River in connection with commercial reactor licensing in the eastern United States, including the licensing of the Vogtle commercial nuclear power plant across the river from Savannah River. Analyses have considered factors such as seismicity—historical earthquake activity—and geological structures near the site. Other analyses have attempted to quantify the magnitude and probability of future occurrences in the area. Studies predict that a major earthquake may not affect Savannah River until over 1,000 years from now. A 1984 NRC-sponsored study predicts that another Charleston-type event could occur about once every 1,500 years. In addition, a DOE Savannah River contractor study estimates the potential of such an earthquake as being even more remote—occurring once every 5,700 years.

The scientific community has not fully researched the geological formations that caused the Charleston earthquake and that exist at the Savannah River Site. In the early 1980s, NRC dealt with this gap in geological knowledge during the Vogtle power plant-licensing process. Questions were raised about whether another "Charleston" might occur with its epicenter elsewhere in the southeastern coastal plain, such as closer to the Savannah River/Vogtle location. However, NRC's assessment of the Charleston earthquake was that it might recur but that its epicenter would not be nearer to the plant site, and therefore it would be felt on-site at a lesser intensity. This assessment was based on a compilation of varying expert views, including those of the U.S. Geological Survey. The Survey takes the position that studies of the problem of the Charleston earthquake's influence on the seismic hazard at critical facilities such as Savannah River should continue. NRC has continued to sponsor research on the issue, but no definitive theory on the cause of the Charleston earthquake has emerged. It is possible that further research could alter the seismic standards DOE uses at Savannah River.

DOE's Savannah River contractor has a research program under way to better determine the geology and earthquake risk at the site. Work was begun in 1987, after several small earthquakes occurred on or near the site in the 1970s and 1980s. The program includes researching the geology of potential or verified faults, and recording and examining seismic activity. In 1988, a fault running across the middle of the site was identified from drilling cores and geophysical logs of wells. Named the "Pen Branch fault," it appears from early investigations not to be associated with geologically recent earthquake activity at the site. Further attempts to delineate the fault are ongoing, and according to DOE officials, the program may continue for several more years.

Objectives, Scope, and Methodology

On October 6, 1988, the Chairman, Environment, Energy, and Natural Resources Subcommittee, House Committee on Government Operations, requested that we examine DOE's ability to ensure employee and public safety at Savannah River in the event of a major earthquake there. Concerns about the site's seismic safety surfaced after an operational incident at P reactor in August 1988 led to scrutiny of the site's overall operating safety.

Our review focused on the ability of the site's reactors and other nuclear facilities to withstand a major earthquake. We examined DOE earthquake design criteria, as well as comparable commercial nuclear industry criteria administered by NRC. Although DOE facilities such as Savannah River are exempt from NRC nuclear safety criteria, DOE has adopted some NRC seismic criteria. In addition, we examined programmatic steps taken by DOE to ensure adequate site seismic protection. We also reviewed recent, ongoing steps to ensure adequate interim seismic protection of the site's reactors so that they may be restarted to produce nuclear materials for defense needs. We examined DOE and contractor seismic guidance, analyses of the site earthquake risk, and program documents and discussed them with DOE and contractor officials at headquarters and in the field. DOE offices contacted included Defense Programs, ES&H, and the Savannah River Site Operations Office. In addition, we discussed seismic issues with officials of DOE's Advisory Committee on Nuclear Facility Safety, NRC, the U.S. Geological Survey, and a representative of the nuclear utility industry and examined NRC seismic studies.

We discussed the contents of this report with agency officials as it was being developed and incorporated their views where appropriate. However, as requested, we did not obtain official comments on the report. Our review was conducted between October 1988 and April 1989, with updating through December 1989, and was performed in accordance with generally accepted government auditing standards.

Evolving Seismic Criteria

Earthquake-engineering standards in the United States have evolved over the years. On the basis of advances in seismology and structural dynamics, the standards have become more stringent. Savannah River was built in the 1950s, before more modern seismic analytic methods and more stringent protection standards were developed. DOE orders provide guidance on what seismic standards should be applied to the design of new facilities. However, they do not give detailed guidance on how DOE should apply newly developed standards retroactively to existing facilities.

Seismic-Engineering Standards Have Become More Stringent

Seismic-engineering standards estimate the motions of the worst earthquake reasonably expected at a site, as well as the response motions of buildings in such an earthquake, and are used in building design to ensure the seismic capability of structures. With advances in the fields of seismology and structural dynamics, these standards have become more stringent over the years.

The worst earthquake reasonably expected at Savannah River is related mainly to the 1886 earthquake near Charleston, South Carolina. The Charleston earthquake is estimated to have had a magnitude of about 7 on the Richter scale at its epicenter—about 80 miles east of the site, where Savannah River now operates. The event caused many deaths and wholesale devastation at Charleston, and many chimneys fell at Augusta, Georgia, about 20 miles northwest of the Savannah River site. Since then, numerous earthquakes have been recorded within 200 miles of Augusta, but none approached the size of the Charleston event. Most registered 3 or below on the Richter scale, and none were above 4.

To put the earthquakes that have occurred at or near the Savannah River Site in perspective, table II.1 shows the severity of earthquakes, based on the Modified Mercalli Intensity Scale. This scale is used to measure earthquake severity when instruments are not available to record ground motion. Since the Richter scale is more commonly referred to in measuring earthquakes, we have included the approximate Richter scale magnitude for comparative purposes.

Table II.1: Earthquake Severity Scales

Mercalli scale	Description of effects	Approximate Richter magnitude
I	Not felt	2
II	Felt by persons at rest, on upper floors	2–3
III	Felt indoors; hanging objects swing; vibration like passing of light trucks	3
IV	Vibration like passing of heavy trucks; windows, dishes, and doors rattle	3–4
V	Felt outdoors; sleepers awaken; small unstable objects displaced or upset	4
VI	Felt by all, frightening many; dishes break, pictures fall from walls; weak masonry cracks	4–5
VII	Difficult to stand; weak chimneys break at roof line; plaster, loose bricks, cornices fall	5–6
VIII	Some masonry walls fall; twisting, falling of chimneys, towers; cracks appear in wet ground	6
IX	General panic; destruction or damage to masonry; serious reservoir damage; sand and mud ejection, sand craters	6–7
X	Most masonry and frame structures destroyed, with their foundations; rails bent slightly	7
XI	Rails bent greatly	7–8
XII	Damage nearly total; large rock masses displaced	8–9

Source: Seismic Analysis, DOE Natural Phenomena Hazards Mitigation Conference Course Guide, 1985.

Site-specific seismic-engineering standards for Savannah River based on the Charleston earthquake did not exist in the early 1950s when the reactors were built. They were built to California construction codes incorporating the ability of structures to withstand earthquake ground shaking of a magnitude equivalent to one-tenth the force of gravity (0.1 "g" acceleration). At the time, the main emphasis was on ensuring that the site's buildings could survive a bomb blast, and limited consideration was given to the seismic reinforcement of systems and equipment in the structures to withstand an earthquake.

Earthquake potential at Savannah River was first subjected to expert analysis in 1967, when a consultant used the 1886 Charleston earthquake as a basis for setting a site ground-shaking standard based on 0.2g acceleration. This standard is the site's worst reasonably expected earthquake (equivalent to the "design basis" earthquake required for siting commercial reactors). This work led to major structural reinforcements of the Savannah River reactors. The 1967 analysis was updated in 1983 to keep abreast of developments in the field. In 1985, standards

were added to predict the response motions of individual floor levels in the reactors.

In recent years, both the 1967 and 1983 standards have been used at Savannah River to upgrade the reactors. However, in 1988 DOE's ES&H questioned whether these standards were stringent enough, and DOE decided to use even more stringent nuclear power plant seismic-engineering standards based in part on NRC requirements for commercial reactors in upgrading the seismic safety of major systems in K reactor. Consultant engineering analysis to develop detailed standards related to this decision was completed in 1989.

DOE Criteria for Seismic Upgrades

DOE has orders stipulating seismic criteria for use in designing its new nuclear facilities. These orders require its new nuclear reactors to meet NRC regulations (10 C.F.R. 50 and 100 seismic design and siting criteria) for the commercial nuclear industry. These regulations require analysis of site geology and earthquake history, quantification of worst expected earthquake potential—in the form of a postulated "design basis" earthquake—and engineering analysis of structures and systems needed to remain functional in the design-basis earthquake. In addition, DOE order 6430.1a requires that the department's new nonreactor facilities be designed to withstand a design basis earthquake and limit the release of quantities of radioactive materials into the surrounding area.

For existing DOE nuclear facilities built to lesser standards, such as several of Savannah River's nuclear facilities, DOE does not have detailed criteria addressing seismic upgrading goals or procedures. DOE orders mention the upgrading option but leave unclear the extent to which the detailed new-facility criteria should be followed for modifications of existing reactors and other nuclear facilities that were built years ago. DOE orders call for safety modifications in cases involving significant safety consequences, and for modifications when adequate safety analysis shows a major on- or off-site potential for impacts on people or the environment. Similarly, DOE has drafted a safety policy which calls for modification on a documented, case-by-case basis, depending on factors such as safety merit, urgency, cost, and facility age.

DOE also has proposed design and evaluation guidelines for protecting new and old DOE facilities against natural phenomena, including earthquakes, which were drafted for ES&H. According to a DOE official, they are still under ES&H review. They attempt to correlate the needed level of protection at facilities to factors such as facility importance, cost, and

hazards to personnel, the public, and the environment. They do not mainly address how to cost-effectively upgrade the seismic capability of existing nuclear facilities not built to the latest standards.

In the summer of 1988, lacking its own upgrading criteria, DOE adapted existing detailed NRC upgrading guidance for use in expedited seismic evaluations undertaken to prepare the Savannah River reactors to be restarted. The NRC guidance was developed in cooperation with the utility industry, and includes evaluation procedures considered to be a cost-effective alternative to requiring older commercial plants to meet the more stringent standards for new plant construction. According to the procedures, plant operators are to assess the resistance of plant equipment by means of visual inspections conducted by expert teams, using as their criteria experiential data on the behavior of similar equipment in earthquakes. Seismic modifications would be based on these inspections.

Site Facilities Inadequately Protected Against a Major Earthquake

Over the last 20 years, projects have been undertaken at Savannah River to seismically analyze its reactors and other facilities, and some upgrades have been undertaken. However, these efforts have been piecemeal, have not always used the most up-to-date engineering standards, and have not been fully documented. DOE analyses show numerous seismic deficiencies in structures, systems, and equipment. Over the years, no comprehensive program has been established at Savannah River to ensure that structures and equipment are systematically analyzed according to current engineering standards and upgraded as warranted. Thus, the seismic upgrades that have been made do not provide assurance that the site's key structures and systems could survive a major earthquake and protect employee and public safety. DOE recognizes the need for a site seismic program, and is planning to implement one for the reactors and other nuclear facilities in phases in coming months and years.

Upgrades Fragmentary, Latest Standards Not Always Used, Modifications Poorly Documented

Over the years, as site seismic engineering standards have evolved, no systematic program to reinforce structures and systems of the site's reactors and other nuclear facilities to meet the new standards has been put in place. The first major reactor seismic analysis was done in 1969 on, among other areas, the

- process section of the reactor buildings,
- reactor and shields,
- reactor supplementary safety system, and
- reactor main process and cooling water piping systems.

While some seismic upgrades have been made in these and other areas, efforts have been piecemeal. A May 1988 safety review by DOE's ES&H found that building and system upgrades were undertaken on a project-by-project basis, without a carefully planned, comprehensive program in place to ensure that as standards evolved, existing facilities were assessed for seismic adequacy. Various management controls were missing: Overall goals and priorities were lacking, essential safety-related components were not defined, and no specific timetable was set for funding their modification. The site's reactors and other nuclear facilities have not been systematically evaluated using adequate DOE modification criteria and up-to-date seismic-engineering standards.

Existing site contractor analyses, done according to differing criteria over the years, show that numerous systems and structures in the reactors and other nuclear facilities may not withstand the worst earthquake reasonably expected at the site. Reactor evaluations have found many seismic deficiencies in bracing of major safety-related systems needed to function during and immediately after an earthquake in order to prevent or mitigate harmful radioactive releases. Weaknesses include supports of the primary, secondary, and emergency cooling-water systems, the electrical instrumentation system, and the airborne radioactivity confinement system. DOE has also determined that the K and L reactors' vent stacks are inadequately supported. DOE is analyzing these weaknesses and undertaking modifications of some systems prior to restarting the reactors. Other modifications will be done in the future. Safety analyses for other nuclear facilities at the site indicate that some of them, such as the existing tritium-loading facility, one of the separations buildings (where desired radionuclides are separated from other fission products), and other separations area facilities, have structural weaknesses that would be of serious concern in a major earthquake.

Up-to-date seismic-engineering standards have not been used in all cases as a basis to upgrade Savannah River facilities and systems. Site seismic design standards were updated in 1967 and 1983 (with floor response standards added in 1985), but DOE has not issued guidance on consistent use of the most current standards. The site contractor established an approach for using the 1983 standards for new construction projects, and the 1967 standards for modifications. However, for major modifications requiring major seismic analysis, the 1983 standards were to be used. The contractor held the view that this approach either met or exceeded NRC's requirements for the commercial nuclear industry. However, in the spring of 1988, DOE's ES&H questioned this approach and was concerned that up-to-date seismic standards were not always being used at Savannah River. In November, as part of the ongoing departmental review of Savannah River operational safety, DOE and the contractor agreed on more stringent engineering standards (based on NRC guidance) to evaluate the interim seismic protection of the site's production reactors. Consultant engineering analyses, needed to fully develop the standards, were completed in 1989. DOE plans to reevaluate these standards as necessary in the course of implementing its planned long-term seismic program at the site.

In addition, control over the engineering documentation of seismic modifications has not been consistently maintained. In March 1988, ES&H inspectors found that control over the accuracy and maintenance of

engineering drawings and documentation of modifications had been seriously neglected. For example, the documentation provided by the contractor as the seismic-engineering analyses-of-record for the site's production reactors was found to be inadequate by ES&H. According to DOE officials, in some cases, analyses were apparently lost or misfiled, and in other cases, they were incomplete. Such analyses are important because they are used to support judgments that the reactors can be operated safely, and without them there is no basis to assess and/or concur in the judgments made. DOE is emphasizing maintenance of up-to-date documentation in its ongoing attempts to improve the reactors' safety so that they may be put back into production.

Need for an Overall Seismic Program

The need for a more comprehensive approach to seismic safety has been recognized at Savannah River but not yet fully addressed. In 1985, based on an inspection of its L reactor, the site contractor saw that upgrades of the production reactors' seismic adequacy would be necessary. Also, in 1987 a DOE review team recommended that Savannah River complete a systematic review of the seismic qualification and bracing of safety equipment in the reactors. Subsequently, the contractor outlined a seismic program. In connection with reactor restart planning, in 1989 the new site contractor developed a long-term seismic program plan for the Savannah River reactors, which is under review by DOE. According to DOE and contractor officials, the plan's intent and scope have been approved, and the plan's details are to be approved and implemented in phases in coming months and years. The plan is a comprehensive approach to reactor seismic safety—including plans for redefining the site's worst reasonably expected earthquake and for upgrading the reactors over several years. Plans are also under way to include nonreactor nuclear facilities at the site in a similar long-term seismic program. At present, interim seismic planning related to restarting the reactors is the highest priority.

Interim Seismic Program Under Way to Upgrade Site Reactors

In June 1988, lacking an overall site seismic program, DOE implemented an interim seismic evaluation effort to satisfy ES&H concerns about seismic safety so that P reactor could be restarted. The effort was an expedited attempt to improve the reactor's seismic resistance, which resulted in numerous reactor modifications to major safety systems. To expedite the inspections, DOE made trade-offs in the stringency of engineering standards and procedures it required for the inspections. In addition, an incorrect engineering factor was inadvertently used in the P reactor inspections, causing invalid results, and the process was not subjected to adequate independent oversight. P reactor is to be reinspected in early 1990 according to more stringent seismic-engineering standards.

After the 1988 P reactor restart attempt, DOE turned its efforts to restarting K reactor. The seismic evaluations of K reactor have shown increased attention to technical issues and oversight. For the K reactor inspections (and those for L reactor, which have been done concurrently), DOE ascertained the interim capability of a minimum number of critical reactor functions as with P reactor, but inspection procedures used were more stringent.

Ineffective Seismic Upgrade of P Reactor in 1988

P reactor was shut down in April 1988 for evaluation and upgrading of its seismic bracing. As these upgrades were being planned, more problems than expected were found, and a DOE ES&H oversight review discovered numerous seismic-related problems concerning the plant's reactors, including the lack of an ongoing seismic program at the site. As a result, a priority effort was begun to define interim modification criteria and engineering standards and make repairs at P reactor to allow the reactor to restart as soon as possible.

Problems With Inspection Procedures

Before a reactor is restarted, DOE reviews its readiness to operate in order to ensure that any needed maintenance or repairs done during shutdown have been adequately completed. For P reactor, the repairs during shutdown were mainly seismic related. Because of concerns raised by ES&H, in the summer of 1988 many DOE, site contractor, and consultant personnel undertook a "novel," "short-term accelerated program" of seismic inspection to upgrade the seismic capability of the reactor. This process led to seismic evaluations of several key safety systems in the reactor and identified several dozen individual repairs to be made.

DOE lacked detailed criteria for such a program and chose to adapt for its use NRC's inspection procedures for upgrading equipment in older nuclear power plants. The procedures called for engineering teams to walk through the reactor and assess the resistance of key individual structures, systems, and pieces of equipment to the worst reasonably expected earthquake at the site. The effort was intended as an interim step to rapidly ascertain the capability of critical safety-related piping and equipment functions in the reactor. More complete evaluations were to be done after the reactor was operational. The site contractor hired several seismic experts to help plan the effort, and others to critique it. ES&H was also actively involved in the seismic planning and operations and provided concurrent, "real time" oversight of the process as it was implemented.

To expedite the inspections, trade-offs in certain requirements were made. For example, DOE made a judgment that the inspections could go ahead although ES&H inspectors questioned whether existing site seismic-engineering standards and analyses were complete and up-to-date. With ES&H concurrence, it was decided that, with some changes, the existing standards could be used for short-term upgrading of the reactor so that it could be restarted, with longer term reevaluation of the standards to be done later.

Also, because as-built engineering drawings for the reactor were inadequate, DOE chose in many cases not to do engineering analyses to support assessments made (as called for in the NRC inspection procedures), relying instead on expert judgments by the inspection teams. DOE, with ES&H concurrence, deemed this approach adequate for an interim seismic inspection to restart the reactor. Physical testing of the strength of seismic bracing in the reactor could have helped to support the expert judgments, but in many cases was not done. Also, inspection teams were not trained in procedures as called for in NRC guidance. In addition, an ES&H official who monitored the inspections said that because of the need to get the reactor restarted, ES&H did not have time to independently check the completed modifications to ensure that they had been properly made.

The inspection was ineffective because an engineering factor (related to the building's absorption or "damping" of an earthquake) was inadvertently misapplied by the inspection teams. The teams used an incorrect, less-stringent-than-intended factor for estimating how the reactor would absorb the effect of the earthquake. According to an ES&H official responsible for overseeing the process, this happened because DOE did

not ensure that guidance was clear and thus there was some confusion. Despite ES&H's concurrent oversight of the effort, it did not discover until September 1988 that the error had been made. P reactor is to be reinspected in early 1990 according to more stringent seismic-engineering standards.

Minimum Functions Upgraded

For the 1988 seismic effort on P reactor, DOE chose to upgrade a minimum number of major functions considered necessary to safely shut down the reactor after a major earthquake. Under the NRC inspection procedures which DOE chose to adapt for use on P reactor, the reactor licensee determines the minimum number of reactor safety systems needed to safely shut down the reactor and maintain it in this condition for 72 hours. For P reactor, the major functions identified by DOE, as required to withstand the worst earthquake reasonably expected at the site (0.2g ground shaking) and safely shut down the reactor, were: Primary reactor vessel cooling, secondary cooling, and automatic "poison ink" injection emergency shutdown capability. In addition, seismically qualified emergency shutdown electrical instrumentation was to be installed. It was also agreed that two major accident-mitigating functions—emergency reactor cooling water and confinement of airborne radioactive contaminants—were not to be upgraded to 0.2g prior to P reactor's restart. They were to be upgraded within a few years.

However, we found that site safety evaluations and ES&H documents indicate that functions involving five or more systems, including emergency cooling and confinement, are needed for safe shutdown of the Savannah River reactors. In fact, DOE's draft safety policy endorses a "defense in depth" safety philosophy regarding reactor operations, including the use of engineered safety features such as emergency cooling and confinement to mitigate potential accidents. DOE officials said they recognized that more than three major functioning systems are important for reactor safety in the event of an earthquake, though not absolutely necessary. DOE chose to upgrade minimal functions for P reactor because of the need to restart the reactor. It was estimated that there was a low risk in operating the reactor for a limited time until further systems could be upgraded. The Advisory Committee on Nuclear Facility Safety was not fully informed of this rationale, partly because it was not yet fully organized, and it was not prepared to comment before DOE attempted to start up P reactor. The committee has since questioned this rationale in connection with K reactor seismic efforts, as discussed in the next section.

The contractor attempted to restart P reactor in August 1988. Operational problems unrelated to seismic safety occurred, which aborted the restart. (Operators responded incorrectly to a restart anomaly, and the incident was not properly reported to DOE.[1]) The restart of P reactor was put on hold, while DOE reviewed technical, human performance, and management issues related to restarting the reactors. The review is expected to continue into 1990.

Seismic Upgrade Efforts for K and L Reactors

DOE has turned to K and L reactors as the next restart candidates, with K reactor first in line. Inspections of these reactors were more rigorous than those for P reactor. According to an ES&H official, the seismic planning for K and L reactors has been "miles ahead" of what it was for P reactor. Attention has also been given to organizational and human performance issues related to the restart. In addition, DOE and site contractor resources have been substantially increased to address the reactors' seismic capability.

DOE turned to restart preparations for K reactor in September 1988 and originally projected its startup to occur at the end of the year. Seismic inspections of the reactor proceeded in October and November. (Inspections for L reactor were done concurrently, though a later restart was planned for it.) For these inspections, DOE ascertained the interim capability of critical reactor functions as with P reactor, but the NRC-based inspection procedures used were made more stringent. As a result, the inspections were more rigorous, with more physical testing of bracing as well as engineering analysis to support the assessments of the inspection teams.

After the inspections were completed, DOE addressed the adequacy of the site's engineering standards. In late November 1988, DOE and the contractor agreed on new standards based in part on more rigorous NRC guidance on how reactor buildings might respond to an earthquake, and to have a consultant do new engineering analyses to verify how the K reactor building would respond in an earthquake. Consultant work was completed and used for confirmatory seismic reinspections of K and L reactors in 1989. According to DOE officials, this analysis and the subsequent reinspections were carefully done, using up-to-date engineering standards, and they resulted in assessments of system resistance that were generally in line with those resulting from the previous inspections

[1]See our testimony, Ineffective Management and Oversight of DOE's P-Reactor at Savannah River, S.C., Raises Safety Concern (GAO/T-RCED-88-68, Sept. 30, 1988).

in the fall of 1988. On the basis of these inspections and reinspections, dozens of deficiencies in major safety-related systems in the reactors have been identified, and modifications are under way.

The functions requiring seismic upgrading for K reactor's restart remain an issue as restart planning proceeds. As with P reactor, DOE plans to seismically upgrade to 0.2g only minimum essential systems relating to three primary safety functions (plus emergency instrumentation) for K reactor's startup—the vessel cooling water, secondary cooling water, and poison ink shutdown systems. This approach was questioned in December 1988 by the Advisory Committee, which has recommended that the reactor's emergency-cooling and confinement systems should also be seismically upgraded prior to restart, in accordance with the principle of "defense in depth" for reactors.

In an internal DOE memorandum, the Deputy Assistant Secretary for Safety, Health, and Quality Assurance has taken the position that upgrades of more than the three primary safety functions to 0.2g are not necessary prior to reactor restart. According to DOE officials, such upgrades could be expensive and, depending on the level of seismic resistance targeted, could take many months to complete, which could further delay restart of K reactor. In subsequent discussions with DOE, the Advisory Committee has said that DOE should do risk-based assessments to justify its choice of systems to be upgraded for the restart of K reactor. A member of the committee said the committee plans to review any such assessment that is made before concurring in a DOE view that emergency cooling and confinement need not be upgraded for the restart. According to DOE officials, such analysis is ongoing and scheduled to be completed before K reactor is restarted. DOE is also doing an overall K reactor seismic safety evaluation in preparation for the reactor's restart, and the Advisory Committee and the Defense Nuclear Facilities Safety Board are involved in reviewing it.

In late 1988 and into 1989, Advisory Committee oversight of K reactor restart planning has been more active than for P reactor. The committee has provided the Secretary of Energy with comments on several technical and management issues, including restart roles and responsibilities. These comments have included criticism of DOE's unclear roles and responsibilities for safety management, raising questions about ES&H's active, hands-on role in helping to solve operational safety problems. As discussed below, in 1989 ES&H assumed less of an operational posture during restart efforts, and as a result of the Secretary's reorganization, ES&H's oversight role is evolving.

ES&H Involved in Operational Planning

In 1988, ES&H acted as a source of seismic and safety management expertise at DOE, in order to expedite solutions to seismic safety issues related to the P reactor startup efforts. ES&H not only exercised concurrent, "real time" oversight of the seismic work on P reactor, but also lent expertise to operational planning for the startup. In doing so, ES&H performed an important function which, according to DOE officials, DOE management at Savannah River and in Defense Programs could not fulfill alone. ES&H officials said that in "wearing two hats" they filled a vacuum of seismic knowledge in other parts of DOE. In addition, DOE has stated that it has limited technical resources to address a wide variety of safety concerns, and a Defense Programs official said that his office could not compete with ES&H resources and expertise in safety management. However, in its dual function prior to the P reactor startup, ES&H was not in the best position to monitor the process and find errors (as noted above) or to exercise independent oversight. An ES&H official said the efforts to upgrade the Savannah River reactors' safety, and especially the P reactor restart process, put ES&H in a peculiar situation, in which it was pressured by program and field office officials to reach a consensus on how to proceed. In addition, as previously discussed, the Advisory Committee was not actively involved in overseeing P reactor restart issues.

For K reactor's startup, ES&H continued to participate in operational planning, as well as functioning in its oversight role. However, according to DOE officials, in 1989 that office assumed less of an operational posture related to the restart.

On May 19, 1989, the Secretary of Energy issued guidance indicating that he planned to reorganize roles and responsibilities for management and oversight of nuclear safety in DOE. Some headquarters and field nuclear safety oversight responsibilities are to shift to the Assistant Secretaries for Defense Programs and Nuclear Energy. In addition, DOE decided that much of the Advisory Committee's nuclear safety oversight role would cease when the newly created Defense Nuclear Facilities Safety Board becomes more fully established in assuming responsibility for overseeing safety at the DOE defense complex. Subsequent to the May announcement, the Secretary created an Office of Nuclear Safety, reporting directly to him, which will have broad responsibilities to monitor and audit all aspects of nuclear safety. According to DOE, no shift will take place until the receiving organizations are staffed and ready to receive their new responsibilities. As of October 1989, the Secretary's reorganization had been implemented for Savannah River operations,

but not fully for other facilities. It remains to be seen how these organizational changes will affect reactor restart preparations and the quality of internal DOE and external safety oversight.

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